Understanding Impulse Bandwidth Specifications of EMI Receivers

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Content

1. Introduction

- When measuring impulsive signals it is **necessary** to know the impulse bandwidth of the receiver's or spectrum analyzer's IF filter

- Due to the nature of impulsive signals some of the spectral components are outside the IF filter passband at any one time

- IF filters of spectrum analyzers are usually defined by their 3 dB or 6 dB bandwidth, which is suitable for measuring CW signals; the bandwidth of EMI receivers used for commercial testing (CISPR 16 Part 1) is specified using a mask defining the magnitude of the filter's transfer function. This is very different from providing a single figure of merit (e.g. 6 dB bandwidth)

- When measuring broadband signals the single bandwidth specification for the IF filter is insufficient since the filter's amplitude and phase response will affect the measurement

1. Introduction

- The comparison of test data, taken with EMI receivers with different IF filter implementations, is very difficult (if not impossible)
- A study, conducted in 1996 in Japan, shows that differences in measurement results of broadband signals up to 6 dB are possible, based on a 3 dB or 6 dB bandwidth specification
- This can lead to a situation where an EUT passes or fails a compliance test, depending on the EMI receiver being used
- Amendment 2 of CISPR 16 Part 1 acknowledges this issue and defines the EMI receiver's resolution bandwidth for measurements above 1 GHz as the **1 MHz impulse bandwidth**

2. Defining Broadband Signals and Impulse Bandwidth

- Characteristics of broadband signals:

  * their frequency spectrum exceeds the receiver's resolution bandwidth
  * usually signals of short duration (e.g. pulses with narrow width)
  * their repetition frequency is substantially less than the receiver bandwidth
  * measured in terms of spectral intensity (*V/MHz* or *dBµV/MHz*)
  * receiver resolution bandwidth is the only criteria that classifies a signal as either narrowband or broadband. In case the IF bandwidth is **changed, the signal classification may change!**

2. Defining Broadband Signals and Impulse Bandwidth

- Impulsive signals cause a transient response in a receiver; the peak value of this response is proportional to the **spectral intensity** of the impulsive signal and to the bandwidth of the receiver

- The exact impulse bandwidth of the receiver must be known in order to measure impulsive signals correctly. This value, unlike the 3 dB or 6 dB bandwidth, is not easily derived from a CW measurement

- The transient behavior of the IF filter depends on the exact shape of the frequency response, the design of the bandpass filter, any logarithmic amplifiers used and any video bandwidth used

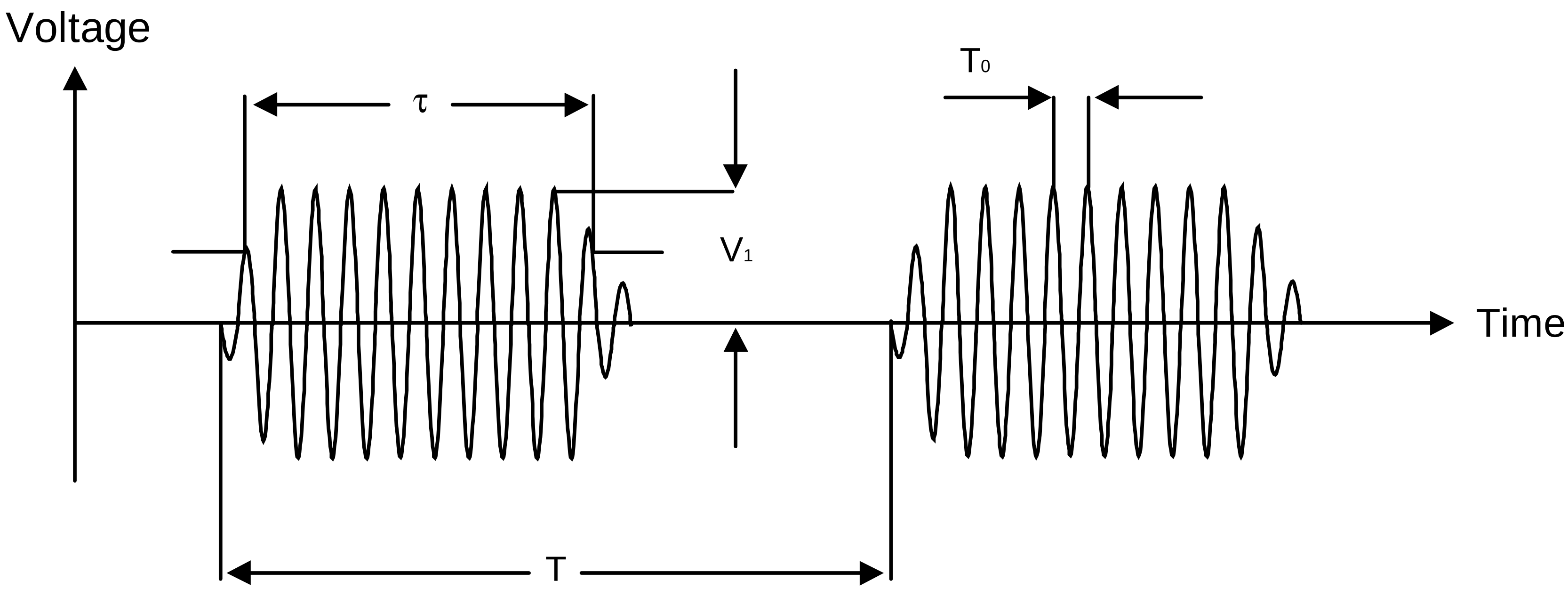
2. Defining Broadband Signals and Impulse Bandwidth

- Impulse bandwidth $\mathbf{BW_i}$ is defined as the ratio of the peak value of the detected transient $\mathbf{V_p}$ and the spectral intensity **S** of the impulse signal causing the transient:

$$BW_i = \frac{V_p}{S} \qquad (1)$$

- Since spectral intensity is specified in RMS volts; V_p must be measured in RMS volts
- The absolute peak voltage must be divided by $\sqrt{2}$; this correction is not necessary if the receiver display is calibrated in RMS values

3. Filtering of a Pulsed RF Signal



τ: pulse width (at 50% points)

$f_r = \frac{1}{T}$; pulse repetition frequency (PRF)

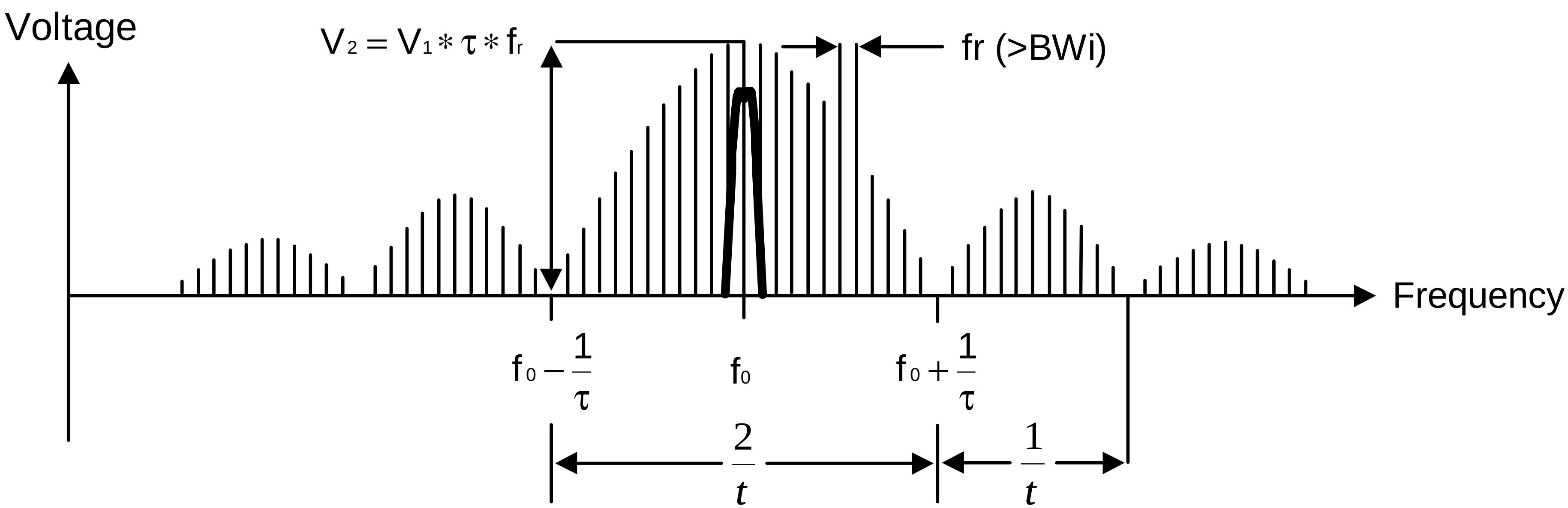
$f_0 = \frac{1}{T_0}$; carrier signal frequency

3. Filtering of a Pulsed RF Signal

- A pulsed RF signal with short duration and a low repetition rate is usually classified as a broadband signal
- Signal has a carrier frequency of f_0 and an RMS amplitude of V_1. The pulse width at the 50% amplitude points is τ and the pulse period T
- If this signal is applied to the input of an EMI receiver the measured result must be interpreted based on the ratio of IF filter bandwidth to the pulse repetition frequency
- When the IF bandwidth is much smaller than the pulse repetition frequency **only one** spectral component is in the filter passband at any one time (narrowband case)
- If the receiver is tuned to the carrier frequency so that the IF filter is centered around the maximum of the main lobe, the RMS amplitude $\mathbf{V_2}$ can be calculated as:

$$V_2 = V_1 * \tau * f_r \qquad (2)$$

3. Filtering of a Pulsed RF Signal



3. Filtering of a Pulsed RF Signal

- If the pulse repetition frequency is smaller than the IF bandwidth of the receiver, many spectral components are within the filter's passband

- If the width of the main lobe of the pulsed RF spectrum is large compared to the IF filter bandwidth ($2/\tau >> BW$) then the spectral components within the passband have approximately constant amplitude. In this case, the spectral intensity of this signal is given by:

$$S = V_1 * \tau \qquad (3)$$

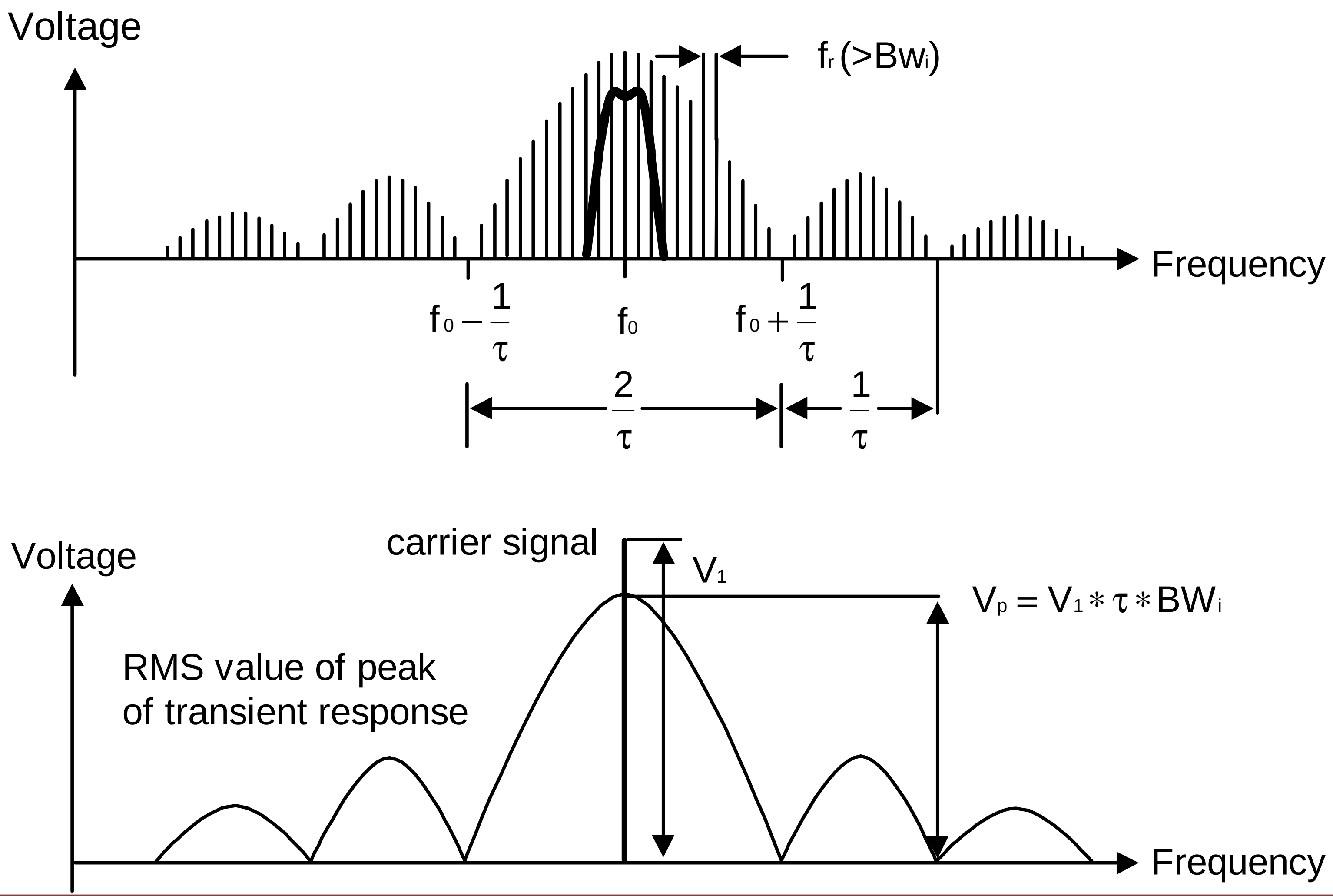
- The maximum output voltage of the RMS value of the peak of the transient response is:

$$V_p = S * BW_i \qquad (4)$$

- Using equation (3) the maximum voltage can be expressed as:

$$V_p = V_1 * \tau * BW_i \qquad (5)$$

3. Filtering of a Pulsed RF Signal



3. Filtering of a Pulsed RF Signal

- Equation (5) is valid as long as the resolution bandwidth is much greater than the pulse repetition rate, and the main lobe width is much greater than the filter bandwidth

- Example clearly shows the necessity for the knowledge of the impulse bandwidth to correctly interpret the result of the broadband measurement

- **V_p** is the maximum detected amplitude of the transient response; **V_1** is the actual peak amplitude of the carrier signal. These are related by the expression:

$$V_p = \alpha * V_1 \qquad (6)$$

- The factor α is called **desensitization factor** and is often expressed in logarithmic terms:

$$\alpha = 20 * \log(\tau * BW_i) \qquad (7)$$

4. Determining an EMI Receiver's Impulse Bandwidth

- The impulse bandwidth of a receiver or spectrum analyzer can be determined using a pulse generator with an accurately known and settable pulse repetition frequency
- The pulse shape must remain constant as the repetition frequency is changed
- When applying the pulse to the receiver or spectrum analyzer to determine the impulse bandwidth, the following must be observed:

  * receiver must be in linear display mode (logarithmic display distorts filter impulse response)

  * front end overload must be avoided by using appropriate input attenuator setting (use attenuator test to check for overload conditions)

  * video or averaging bandwidth must be set at least three times as wide as the resolution bandwidth to avoid any averaging effects

4. Determining an EMI Receiver's Impulse Bandwidth

- In the first step of the impulse bandwidth measurement the pulse repetition frequency $\mathbf{f_{R1}}$ is set to a value much higher than the resolution bandwidth of the instrument (factor 3 min.)

- The amplitude of the signal $\mathbf{V_2}$ is measured with the receiver tuned to the PRF or one of its harmonics. Only one spectral component will be in the filter passband and the amplitude can be calculated as:

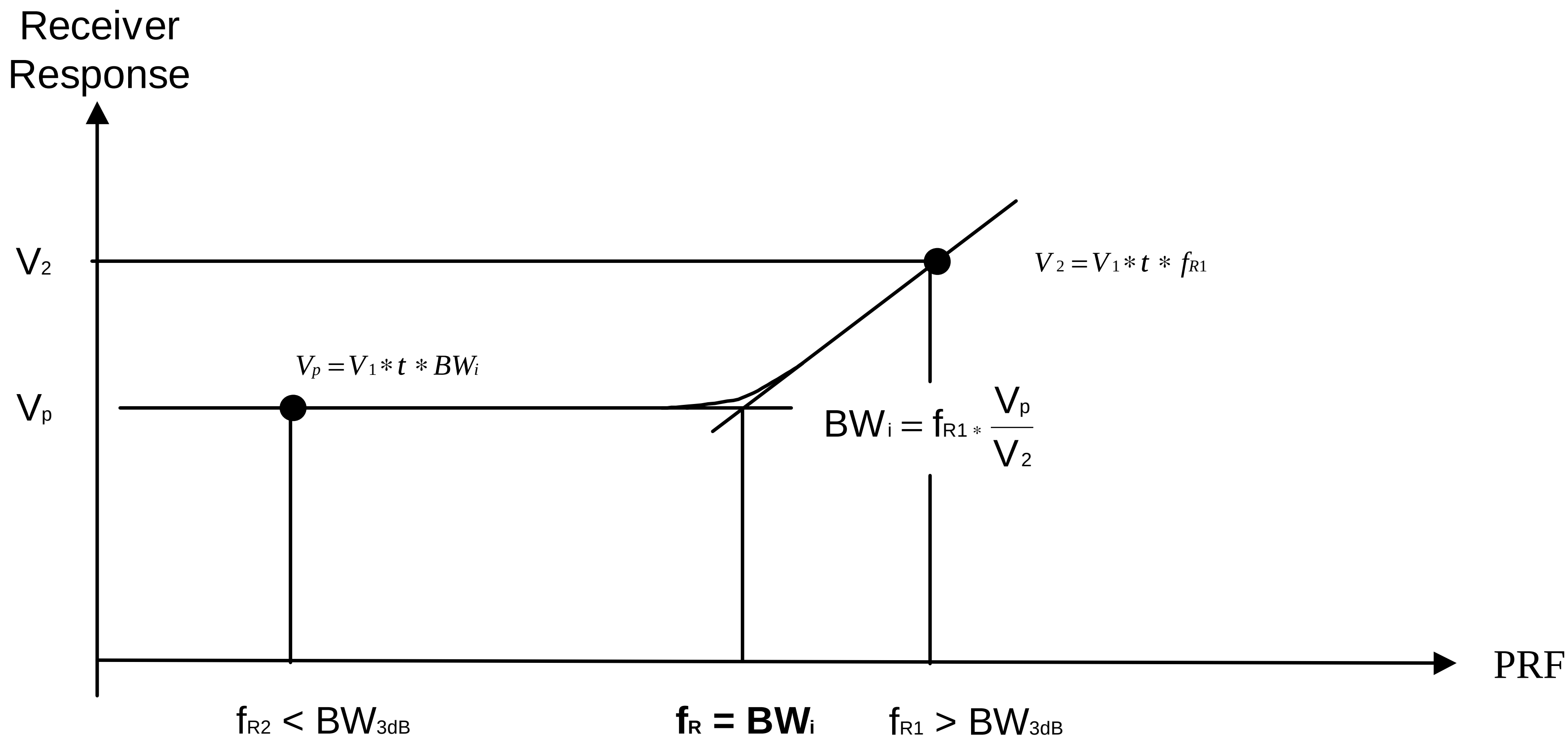
$$V_2 = V_1 * \tau * f_{R1} \qquad (8)$$

- In the second step the PRF is reduced to a rate $\mathbf{f_{R2}}$ which is much smaller than the resolution bandwidth (factor 10 min.) and the pulse shape must remain constant

- The amplitude $\mathbf{V_p}$ is measured again at the same tuning frequency. Several spectral components will be in the filter's passband and the amplitude can be calculated as:

$$V_p = V_1 * \tau * BW_i \qquad (9)$$

4. Determining an EMI Receiver's Impulse Bandwidth



4. Determining an EMI Receiver's Impulse Bandwidth

- By combining equations (8) and (9) the impulse bandwidth can be calculated as follows:

$$BW_i = f_{R1} * \frac{V_p}{V_2} \qquad (10)$$

- The pulse width for the second step must be selected narrow enough to ensure a flat spectrum in the filter passband. The pulse width must also be wide enough that the signal will be sufficiently above the noise floor to avoid measurement inaccuracies

- The advantages of this method of impulse bandwidth measurements are:

  * spectral intensity of the pulse need not be known

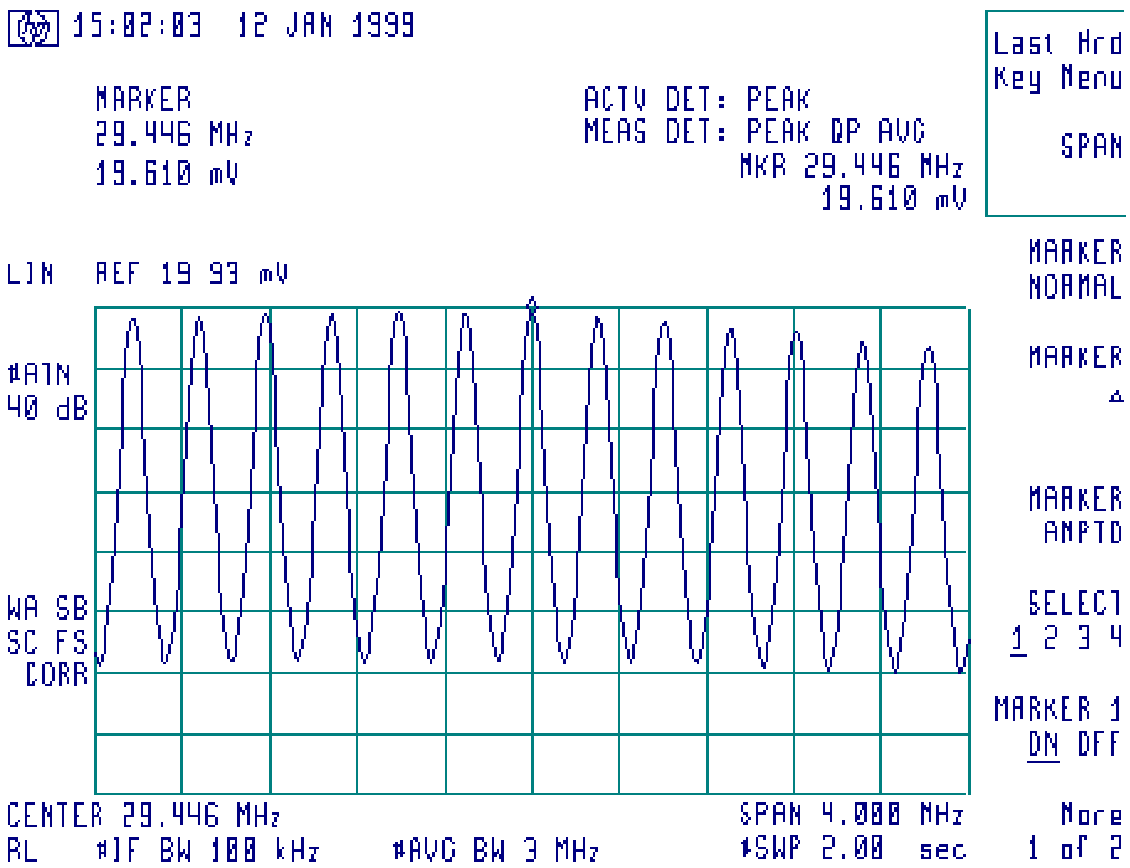
  * any pulse shape can be used (modulated or unmodulated)

5. Measurement Example

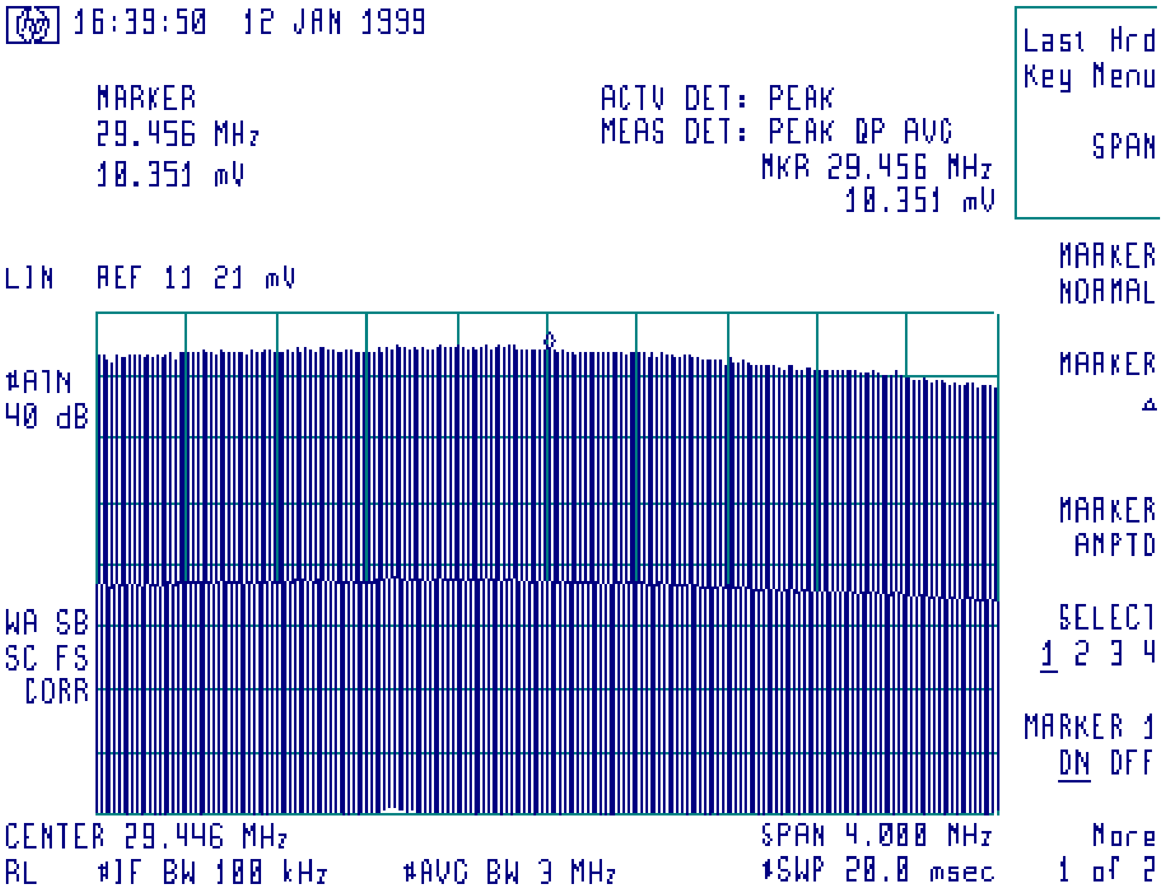
- The previously suggested method was used to determine the impulse bandwidth of the 100 kHz (3 dB) IF filter of a spectrum analyzer
- A pulse generator which met the previously described criteria was used and the following instrument settings chosen:

pulse width τ:	50 ns
pulse amplitude V_p:	5V
rise time t_r:	2 ns
fall time t_f:	2 ns
PRF (narrowband) f_{R1}:	3*RBW (300 kHz)
PRF (broadband) f_{R2}:	0.1*RBW (10 kHz)

5. Measurement Example



5. Measurement Example



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5. Measurement Example

- The voltage level for the 300 kHz PRF measurement was recorded to be 19.61 mV; for the 10 kHz PRF measurement a value of 10.35 mV was measured

- The impulse bandwidth of the 100 kHz (3 dB) IF filter was calculated as follows:

$$BW_i = 300\,kHz * \frac{10.35\,mV}{19.61\,mV}$$
$$= 158.3\,kHz$$

- The accuracy of this procedure can be improved further by selecting a pulse amplitude where both measurements can be made without changing instrument settings, especially the reference level. Due to the ratioing, the display fidelity is the remaining dominant factor

6. Regulatory Situation

EMI receiver bandwidths are specified differently in various standards:

CISPR 16 Part 1 (1999-10)

Par. 4.1.2:	9 kHz	to	150 kHz	200 Hz	(6 dB, mask)
	150 kHz	to	30 MHz	9 kHz	(6 dB, mask)
	30 MHz	to	1 GHz	120 kHz	(6 dB, mask)
Par. 5.4.2.a	1 GHz	to	18 GHz	1 MHz	(impulse bandwidth)

ANSI C63.2 (1996)

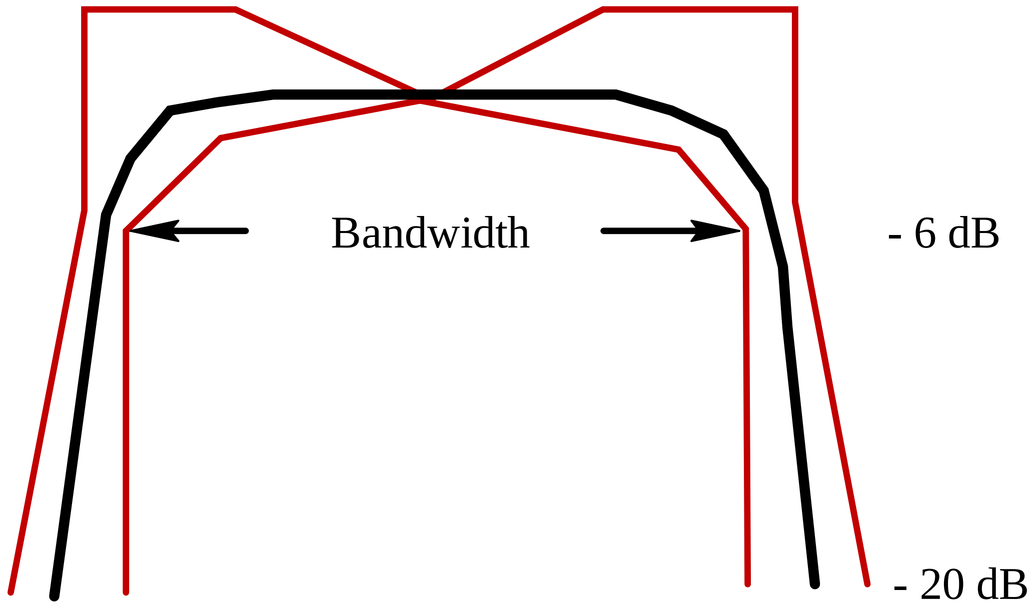
Par. 4.1.	9 kHz	to	150 kHz	200 Hz	(6 dB, mask)
	150 kHz	to	30 MHz	9 kHz	(6 dB, mask)
	30 MHz	to	1 GHz	120 kHz	(6 dB, mask)
Par. 5.4.2.a	1 GHz	to	18 GHz	1 MHz	(6dB)

MIL-STD 462D (1993), 461E (1999)

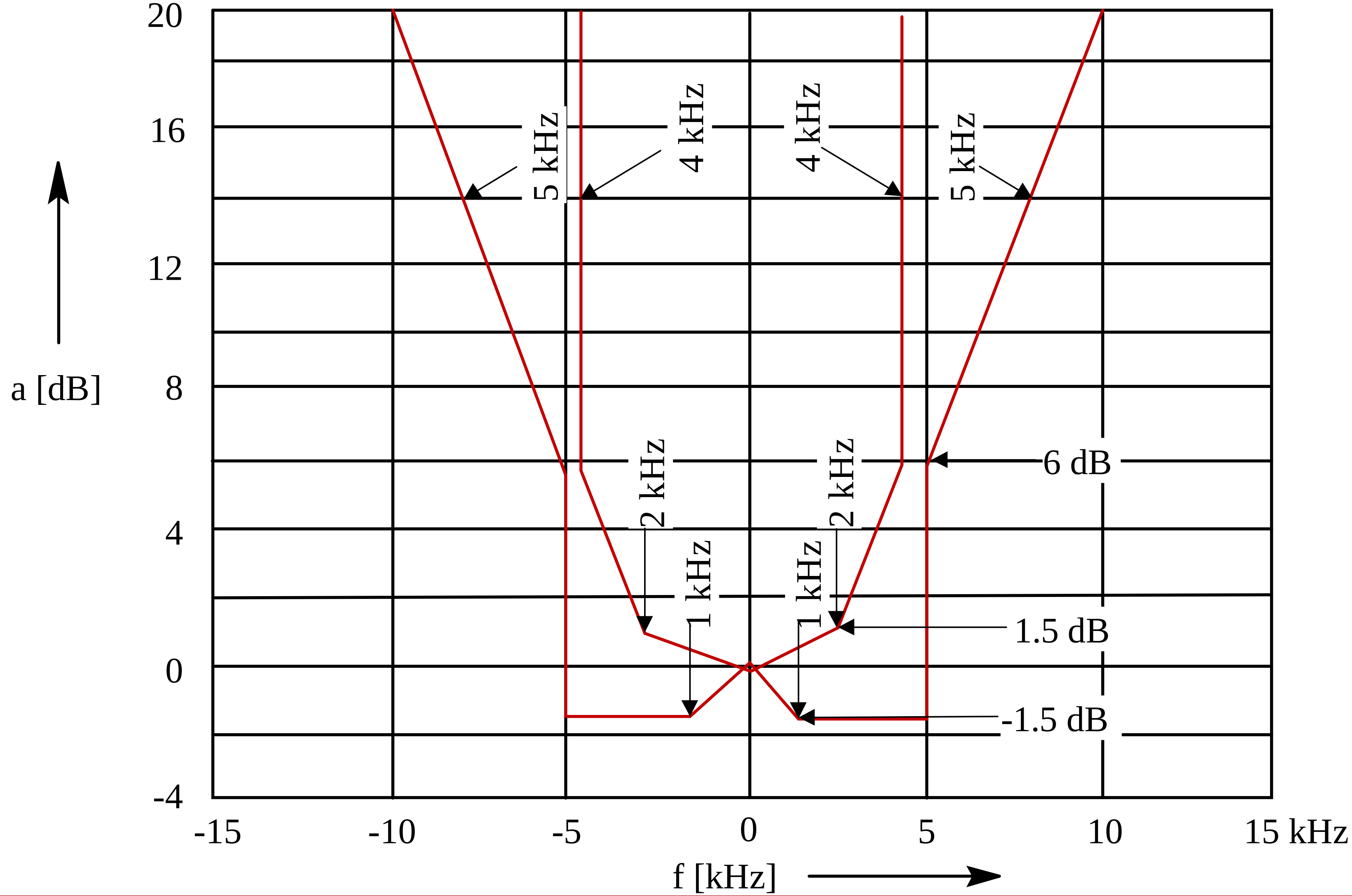
Par. 4.10.3.1. (462D)	30 Hz	to	1 kHz	10 Hz	(6 dB)
Par. 4.10.3.1. (461E)	1 kHz	to	10 kHz	100 Hz	(6 dB)
	10 kHz	to	250 kHz	1 kHz	(6 dB)
	250 kHz	to	30 MHz	10 kHz	(6dB)
	30 MHz	to	1 GHz	100 kHz	(6dB)
	above 1 GHz			1 MHz	(6dB)

6. Regulatory Situation

EMI receiver bandwidth per CISPR 16 Part 1 (1999-10) for
9 kHz to 1 GHz frequency range

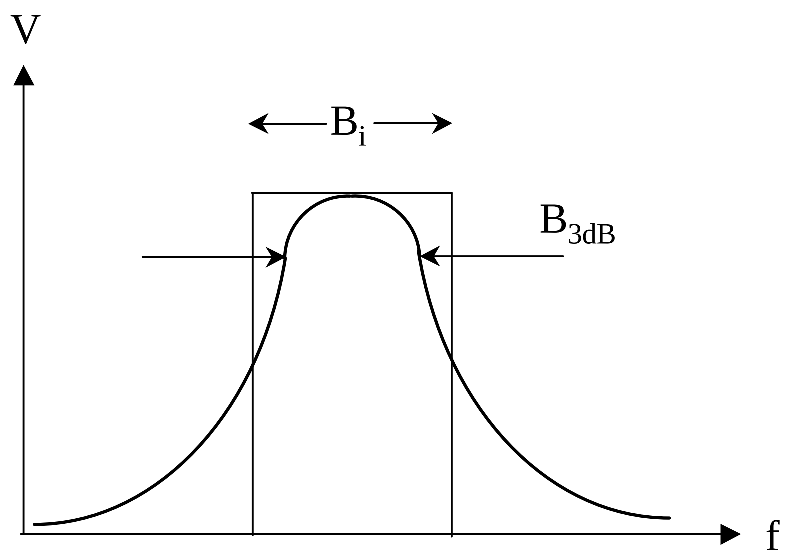


6. Regulatory Situation



6. Regulatory Situation

- Specification of a filter mask is much more rigorous than defining a bandwidth and filter type
- The impulse bandwidth specification is very similar to specifying a filter mask! It is defined as the bandwidth of an ideal rectangular filter which has the same voltage response as the actual measurement filter.



7. Summary

- EMI receivers and spectrum analyzers are used to measure both narrowband and broadband signals. This requires the knowledge of the impulse bandwidth to correctly interpret the broadband measurement result
- The broadband signal amplitude is directly proportional to the IF filter's impulse bandwidth and **not** its 3 dB or 6 dB bandwidth
- A very simple and reliable method for determining the impulse bandwidth of any filter is available which involves minimal additional test equipment
- Using the proposed method, the impulse bandwidth can be calculated from measurement values and pulse generator settings